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Influence of Finishing Materials on Viscous Elastic Properties of Wooden Structures

Utjecaj premaznih materijala na viskoelastična svojstva drvenih elemenata

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ABSTRACT • *In this study, the effect of finishing process on the mechanical properties of oak and pine wood elements were investigated. A special test stand was used for this purpose. Specimens were divided into subgroups, the resonance frequency of the specimens was determined (when they vibrate in mode of a theoretic isotope beam), and the modulus of elasticity (MOE) and damping coefficient were estimated. It was determined that MOE of oak and pine specimens was 8415-10570 MPa and 8220-14104 MPa, respectively, while damping coefficients were 0.014-0.019 r. u. and 0.013-0.026. Afterwards, some specimens were varnished (pentaftal varnish was used), while the specimens from others subgroups were oiled (water-based outdoor wood oil was used) and after each processing step, the viscous elastic properties of the specimen were recorded. The specimens were finished four times – first, one side was finished in two layers, and then the other side. For the determination of elastic properties of the finishing materials, films were prepared separately. The film formation was carried out by casting liquid on a smooth, siliconised surface of a test panel. The tensile test was carried out using the universal testing machine. It was established that MOE of films varied in the range of 4-7 MPa. After the varnishing process, the MOE of oak and pine elements decreased by 5 % and 7 %, respectively, while the damping coefficient decreased (in varnish case) by 60 %. The impact of oil on viscous elastic properties of the specimens was quite marginal.*

Keywords: *oak wood, pine wood, modulus of elasticity, damping coefficient, finishing materials, pentaftal varnish, wood oil*

SAŽETAK • *U radu je istraživan utjecaj procesa površinske obrade na mehanička svojstva hrastovine i borovine. Za istraživanje je pripremljeno posebno postolje. Uzorci su podijeljeni u dvije podskupine, utvrđena je njihova rezonantna frekvencija (kada vibriraju u modu teorijskog snopa izotopa) te su procijenjeni modul elastičnosti (MOE) i koeficijent prigušenja uzoraka. Utvrđeno je da je MOE uzoraka od hrastovine 8415 – 10 570 MPa, uzoraka od borovine 8220 – 14 104 MPa, a koeficijent prigušenja iznosio je 0,014 – 0,019 r. u., odnosno 0,013 – 0,026. Nakon toga dio uzoraka je lakiran (upotrijebljen je pentaftalni lak), a uzorci iz druge podskupine premazani su uljem (uljem na bazi vode za vanjsku primjenu). Nakon svakog procesa obrade uočena su viskoelastična svojstva uzoraka. Uzorci su premazani ukupno četiri puta – najprije je u dva sloja premazana jedna, a zatim druga strana uzoraka. Za određivanje elastičnih svojstava premaznih materijala posebno su pripremljeni filmovi, i to nalijevanjem premaznog materijala na glatku, silikoniziranu površinu ispitne ploče. Vlačno ispitivanje obavljeno je na*

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univerzalnom uređaju za mehanička ispitivanja. Utvrđeno je da MOE filmova varira u rasponu od 4 do 7 MPa. Nakon lakiranja MOE hrastovih elemenata smanjio se za 5 %, borovih elemenata za 7 %, a koeficijent prigušenja na lakiranim uzorcima smanjio se za 60 %. Ulja su neznatno utjecala na viskoelastična svojstva uzoraka.

Ključne riječi: *hrastovina, borovina, modul elastičnosti, koeficijent prigušenja, premazni materijali, pentaftalni lak, ulje za drvo*

1 INTRODUCTION
1. UVOD

The elements of wood and wood-based materials are widely used in building structures and interior products. The durability of wood for outdoor use is not only affected by climatic factors but also by mechanical properties of wood, which to a large extent depend on the finish. The complex effect of the mechanical and physical properties of wood and environmental factors determines the durability of wooden structures and other wood-based products. Depending on the purpose, wooden structures must exhibit appropriate mechanical properties, which are often subject to legislation, building regulations and standards. In some cases, the structures must be elastic and resistant to various mechanical loads, in other cases, on the contrary, they must be able to dampen vibrations and sounds, as well as have inhibitory properties (Forssén *et. al*., 2008; Botterman *et. al*., 2018).

The mechanical properties of these kinds of structures are determined by the mechanical properties of their individual elements and the composition method of their interconnection (Taghiyari *et al*., 2017; Souza da Rosa *et. al*., 2017; Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004). It is known that the modulus of elasticity (MOE) and damping coefficient of a glued wood panel depends on the properties of the glued wood scantlings (Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004). Once a scantling, which is characterised by a higher MOE, is glued to the panel, the MOE of the whole panel becomes higher, and vice versa. A lower MOE and a higher damping coefficient of the glued product than the average value of the total number of glued scantlings show that the product probably contains defects, e.g. that the seams were poorly glued together, etc.

The viscous elastic properties of the elements of wooden structures can be altered, e.g. by changing the surface area of the element (i.e. by creating grooves, notches, etc.) (Ono, 1993; Molin *et. al.*, 1984; Molin *et. al*., 1988), by soaking them (Endo *et. al*., 2010) and using finishing materials of different properties.

It was determined that different components of wooden composites and manufacturing technology can also have an effect on their mechanical properties (Taghiyari *et al*., 2017).

Also, overlays have a large effect on the mechanical properties of particleboard (Vobolis and Albrektas, 2012). Depending on the orientation/direction of the overlay material (especially on sliced veneer of natural wood), the MOE of a finished particleboard can be increased or decreased in the direction concerned. This can be explained by the fact that the viscous elastic properties of natural wood can vary up to 20 times in different fibre directions.

Nowadays, the market offers various finishing materials of wood. Therefore, there is a lack of comprehensive research that evaluates the influence of finishing materials on the properties of wood-based products.

The aim of this study is to evaluate the influence of finishing materials on viscous elastic properties of wooden structures and their elements.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The research study used conditioned specimens of oak (*Quercus robur*) and pine (*Pinus sylvestris*) wood, which were stored in a climatic chamber for 336 hours at a temperature of 20 ± 1 °C, and a relative humidity of 60 ± 2 % (standard EN 408, chapter 8). The dimensions of the researched specimens were 700 mm ×100 mm ×16 mm, with moisture content ranging between 10.4 and 11.2 % (standard EN 13183-2). According to the standard EN 323, the density of the specimens was measured and the results showed that oak wood had a density ranging between 650 and 760 kg/m^3, whereas the density of pine wood ranged between 460 and 570 kg/m^3.

For finishing the specimens, two types of material were used: pentaftal varnish and water-based outdoor wood oil, based on water and natural oils. The amount of non-volatile substances of the varnish is 46 ± 3 %, whereas the amount of non-volatile substances of the oil is 21 %. The pentaftal varnish, which is based on alkyd resins, covers the wood surface with an elastic film that suppresses liquids; however, it allows steam to penetrate and it is resistant to atmospheric agents. The water-based wood oil soaks into the wood surface and serves as protection from humidity and dirt.

A special test stand (Figure 1) was used to determine the MOE and damping coefficient on the basis of non-destructive testing (transverse resonant vibrations) method, which also allowed assessing the mechanical properties of the specimens (Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004). Loudspeaker 4, controlled by the generator of electric oscillations 5, excites resonance oscillations of the specimen 1. For this purpose, the frequency of the generator's oscillations is changed. These oscillations are recorded by the sensor 6, fixed on the specimen. Their amplitude is measured using device 7. To ascertain the direction of specimen bending, the phase of oscillations is measured by a phase meter 9. The phase meter receives the signal from the measuring device and generator. For a more accurate ascertainment of the form of bending, several zones of specimen were chosen. In these zones

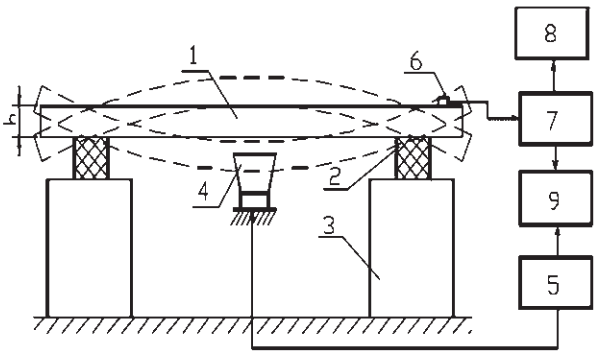


Figure 1 Scheme of test stand:1 - specimen; 2 - vibration damping material (foam rubber); 3 - massive supports; 4 - loudspeaker; 5 - vibration generator; 6 - sensor; 7 - measuring instrument; 8 - oscilloscope; 9 - phase meter
Slika 1. Shema ispitnog postolja: 1 – uzorak; 2 – materijal za prigušivanje vibracija (pjenasta guma); 3 – masivni nosači; 4 – zvučnik; 5 – generator vibracija; 6 – senzor; 7 – mjerni instrument; 8 – osciloskop; 9 – fazni mjerač

the measuring element was fixed and oscillations were recorded, i.e. their amplitude and phase were measured. By determining the corresponding (first mode) frequency, a MOE is calculated. By determining two other frequencies, when the vibrational amplitude decreases by 0.7 times, the damping coefficient is calculated. The studies were performed at a frequency of 20-2000 Hz.

The MOE was calculated by the following Eq. 1 (Timoshenko *et al*., 1985):

$$E = \frac{f_{\mathrm{rez}}^2 \cdot 4\pi^2 \cdot \rho \cdot s \cdot l^4}{I \cdot A^2} \tag{1}$$

Where: E – modulus of elasticity, f_{rez} – frequency of transverse vibrations, ρ – density of wood, s – cross-sectional area, l – beam length, I – cross-sectional moment of inertia, A – method of fastening represented by a coefficient.

The viscous properties of studied specimens were evaluated by damping coefficient, calculated by the following Eq. 2:

$$tg\delta \approx \frac{\Delta f}{f_{\mathrm{rez}}} \tag{2}$$

Where: f_{rez} – frequency of transverse vibrations, Δf – frequency bandwidth, when the amplitude of vibrations decreases by 0.7 times.

In order to evaluate the influence of finishing materials on viscous-elastic properties of wooden structures, the specimens were covered with two types of products for wooden surfaces. The finishing materials were applied to the specimens following the recommendations of the manufacturers. Prior to application, the specimens were stored at 23 ± 2 °C temperature and 50 ± 5 % relative humidity for 24 h. The surface of the specimen intended for covering was clean and free from distortion and other defects. The finishing material was applied with a brush in 2 layers (stepwise) on both sides of the specimen. After each application of the layer, the specimen was dried for 24 hours under the above temperature/humidity conditions in accordance with manufacturer's instructions without prejudice to EN 23270.

For the determination of elastic properties of finishing materials, films were prepared separately, consisting of wood varnish and oil, which were used for the study. The film was formed by casting liquid on a smooth, siliconised surface of a test panel. The casting was dried for 7 days at 23 ± 2 °C temperature and 50 ± 5 % relative air humidity. The film formation process was completed by removing it from the test surface. Afterwards, the film-coated specimens were cut to determine the modulus of elasticity. Ten specimens of varnish and the same number of oil specimens were cut for tensile test. The uniformity of film specimens was ensured by measuring the thickness, which was on average 0.30 mm in the case of varnish and 0.19 mm in the case of oil. The tensile test was carried out using the universal testing machine BTI FB-050 TN (Zwick). The gripping distance was 100 mm and the constant speed for the grips was 100 mm/min.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

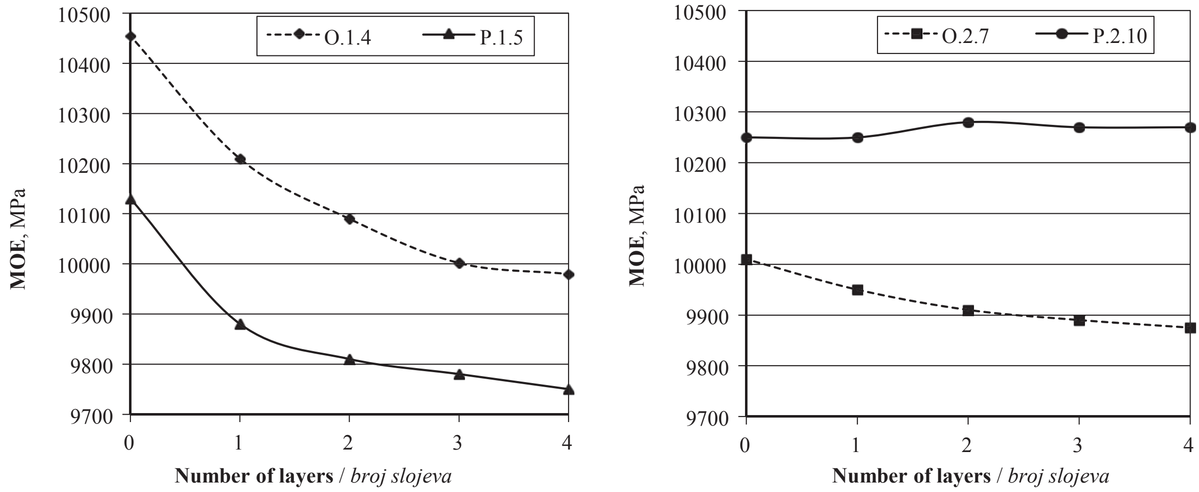
After completing the conditioning process, the specimens were divided into subgroups (oak specimens were divided into O.1 and O.2, whereas pine specimens were divided into P.1 and P.2), the resonance frequency of the specimens was determined (when they vibrate in mode of a theoretic isotope beam) (Timoshenko *et al*., 1985), and the MOE and damping coefficient were estimated. The results are displayed in Table 1.

The estimated values of the MOE and damping coefficient of wood correspond to the values that are well-known in literature (Wagenführ, 2000; Wood Handbook, 2010).

The analysis of the viscous properties of the finishing films showed that the MOE of wood varnish and oil varies in the range of 4-7 MPa with a variation of

Table 1 Values of resonance frequency, MOE and damping coefficient of specimens before finish was applied
Tablica 1. Vrijednosti rezonantne frekvencije, modula elastičnosti i koeficijenta prigušenja uzoraka prije površinske obrade

Subgroup *Podskupina*	**Resonance frequency,** Hz *Rezonantna frekvencija,* Hz		**MOE,** MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u.	
	Min	Max	Min	Max	Min	Max
O.1	114	142	8415	10570	0.014	0.031
O.2	118	130	8520	10010	0.016	0.019
P.1	132	176	8220	14104	0.013	0.026
P.2	136	159	8650	12430	0.013	0.017



a) b)

Figure 2 Variations of specimens MOE by increasing the number of layers of the finishing material: a) varnish finish; b) oil finish; these are unique identification numbers of specimens –O.1.4, P.1.5, O.2.7, P.2.10.

Slika 2. Varijacije modula elastičnosti uzoraka s povećanjem broja slojeva premaznog materijala: a) lak; b) ulje; oznake uzoraka su O.1.4, P.1.5, O.2.7, P.2.10.

10.6 %. These values correspond to the values that are well-known in literature (Mironeet *et al*., 2004; Ghaznavi *et. al*., 2013; Wawro and Kazimierczak, 2008).

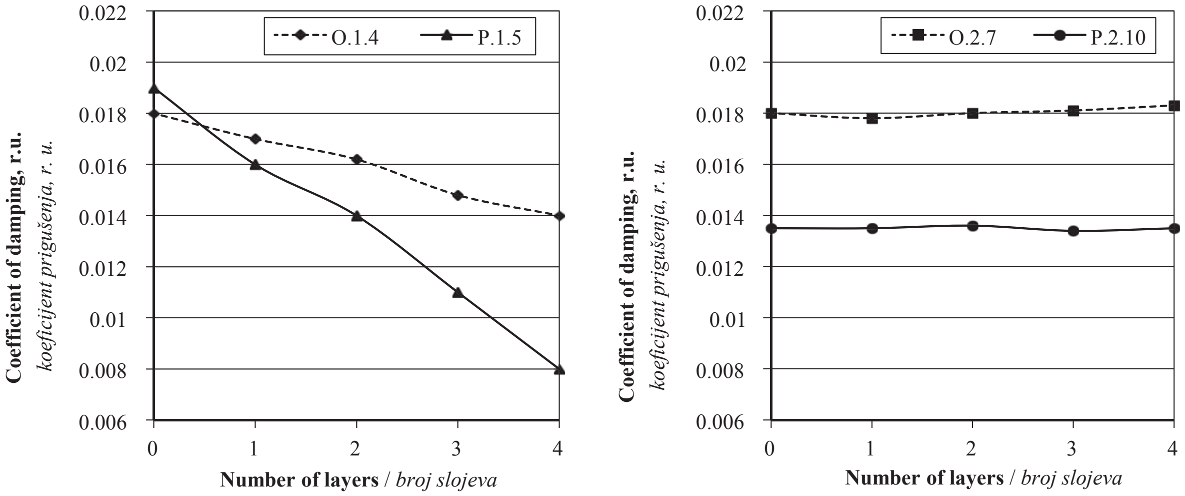
Afterwards, the specimens from subgroups O.1 and P.1 were varnished, while the specimens from subgroups O.2 and P.2 were oiled using the test finishing materials, and after each processing step, the viscous elastic properties of the specimen were recorded. Each subgroup is appropriately represented by the variation of the MOE and damping coefficient of the specimens in Figures 2 and 3.

The values of the mechanical properties of all the specimens before and after the finishing treatment are provided in Tables 2 and 3.

According to these results (Table 2), it was estimated that between the minimum and maximum value in the same group of specimens, the MOE of oak wood specimens before and after varnish finish can vary up to 23 %, whereas the results before and after oil finish show that the difference between the maximum and minimum value is no larger than 15 %. Before using the varnish finish on oak wood specimens, the values of the damping coefficient in the same group can vary more than 50 %. After using the varnish finish, the difference between the minimum and maximum damping coefficient was reduced to 37 %. The use of this finishing treatment reveals that the damping coefficient of the specimens was reduced in all cases. The outcome was a little different in the group that was treated with oil finish. After applying the oil finish, the damping ratio was practically left unchanged, and in some cases, the results showed a slight increase or decrease.

The equivalent results were retrieved by analysing the tests results of pine wood specimens. The use of oil finish on pine wood specimens proved to have no effect on the damping coefficient, since in nine out of ten cases, after applying the oil finish, the damping coefficient of the specimens remained unchanged.

It was determined that, after the varnishing process, the mass of oak wood specimens increased by 9-14



a) b)

Figure 3 Variations of damping coefficient of specimens by increasing the number of layers of the finishing material: a) varnish finish; b) oil finish

Slika 3. Varijacije koeficijenta prigušenja uzoraka s povećanjem broja slojeva premaznog materijala: a) lak; b) ulje

Table 2 Mechanical properties of oak wood specimens before and after the finishing treatment
Tablica 2. Mehanička svojstva uzoraka hrastovine prije i nakon površinske obrade

Specimen No. *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u.		**Speci-men No.** *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u	
	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*		Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*	Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*
O.1.1	9733	9380	0.031	0.017	O.2.1	9505	9215	0.018	0.019
O.1.2	8655	8390	0.030	0.017	O.2.2	8945	8610	0.017	0.018
O.1.3	10010	9720	0.023	0.012	O.2.3	9775	9420	0.017	0.018
O.1.4	10455	9980	0.023	0.019	O.2.4	8652	8550	0.018	0.018
O.1.5	9352	8883	0.018	0.014	O.2.5	9595	9230	0.019	0.020
O.1.6	8415	8002	0.017	0.014	O.2.6	8883	8790	0.018	0.018
O.1.7	10570	10357	0.014	0.012	O.2.7	10010	9875	0.018	0.018
O.1.8	8942	8758	0.025	0.017	O.2.8	8995	8850	0.018	0.018
O.1.9	10251	10040	0.015	0.012	O.2.9	8520	8350	0.019	0.018
O.1.10	9522	9320	0.016	0.014	O.2.10	8811	8720	0.016	0.017

■ – the maximum group value / *najveća vrijednost skupine,* □ – the minimum group value / *najmanja vrijednost skupine*

Table 3 Mechanical properties of pine wood specimens before and after finishing
Tablica 3. Mehanička svojstva uzoraka borovine prije i nakon površinske obrade

Speci-men No. *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u.		**Specimen No.** *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u	
	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*		Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*	Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*
P.1.1	14104	13790	0.017	0.011	P.2.1	9320	9305	0.014	0.014
P.1.2	11810	11500	0.019	0.013	P.2.2	12430	12425	0.013	0.022
P.1.3	13260	12950	0.019	0.013	P.2.3	9290	9305	0.014	0.014
P.1.4	12720	12450	0.015	0.010	P.2.4	8880	8830	0.016	0.016
P.1.5	10130	9750	0.019	0.008	P.2.5	8725	8705	0.014	0.014
P.1.6	9082	8450	0.013	0.007	P.2.6	12210	12190	0.015	0.015
P.1.7	13070	12130	0.013	0.009	P.2.7	11510	11480	0.013	0.013
P.1.8	9687	9315	0.026	0.019	P.2.8	8950	8915	0.015	0.015
P.1.9	8220	8045	0.015	0.011	P.2.9	8650	8625	0.017	0.017
P.1.10	15050	14210	0.024	0.012	P.2.10	10250	10270	0.014	0.014

■ – the maximum group value / *najveća vrijednost skupine,* □ – the minimum group value / *najmanja vrijednost skupine*

g (on average approximately 1.5 % of the specimen mass). In all cases, the MOE decreased by 1-5 %, whereas the damping coefficient decreased by 15-50 %.

The results show that the mass of the varnished pine wood specimens increased by 13-21 g (on average approximately 3.3 % of the specimen mass). A higher mass change also implied a change in the mechanical properties of the specimens – the MOE decreased by 2-7 %, while the damping coefficient decreased by 30-60 %. Pine wood could absorb more varnish, since it has a lower density and its capillary system can encompass a higher relative volume of the whole specimen.

It was established that the mass of the oiled oak wood specimens increased by 7 g, while in the case of pine, it increased by only 4 g, i.e. it altered less than 1 % of the specimen mass. It can be assumed that the impact of oil on the viscous elastic properties of the specimens was quite marginal. The MOE of oak specimens decreased by 1-4 %, the damping coefficient increased by 5 %, whereas the MOE and damping coefficient of pine specimens were ultimately left unchanged – the values varied within a 1 % range.

A clear reliance of the impact of the finishing material on a varied density of the same type of specimens was not determined. Also, there is no evidence of a linear relationship between the amount of finishing material for the specimen finishing procedure and the change of the viscous elastic properties. Moreover, there was also the influence of other factors, such as the uniformity of coating thickness of the finish, the depth of penetration, etc.

The decrease of the MOE of the finished specimens can be explained by taking into account that the

MOE of the finishing materials is significantly lower (4-7 MPa) than that of natural wood (8220-14104 MPa) (Table 1). Furthermore, the finishing materials, especially varnish, can improve the acoustic properties of wood elements (Ono, 1993).

4 CONCLUSIONS
4. ZAKLJUČAK

It was established that the finishing materials can alter the viscous elastic properties of wooden structure elements. Moreover, this effect is proportional to the amount of used material but not directly depend on the mass of the finishing materials. When the varnish formed 2 % (oak) - 5 % (pine) of sample mass, the MOE decreased by 5-7 percent, respectively. The damping coefficient in these cases decreased to 30-60 percent. The oil formed a smaller part of the specimen and its influence on mechanical properties was lower.

It was estimated that the finishing material (oil and varnish) amounted to a considerable fraction of the total mass of the finished specimen (at least 1.5 %), and in all cases, its modulus of elasticity and damping coefficient decreased. This can be explained by the fact that the modulus of elasticity of finishing material is lower in relation to wood lengthwise fibre.

It was determined that a substantial amount of the finishing material (varnish) can improve the acoustic properties of a wooden element. An unvarnished wooden structure can dampen the sound more effectively than a varnished one.

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